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Supervisory Control Information Management Research (SCIMR) Studies: Study of Hotkey Operation Relative to Touch Commands in Utility Tasks (SHORTCUT)

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14. ABSTRACT
This study investigated the effectiveness of hotkeys on a game pad (used with a standard mouse) and multi-touch in comparison to the standard mouse. The devices were the standard mouse and Belkin n52te, a 3M 22-finger multi-touch monitor, and the standard mouse alone. Participants were assigned one of these device configurations to complete 2 trials, an N-shaped maze and a spiral maze, each paired with simpler secondary tasks on the other side of the screen. The mazes had treasures to collect, attackers to avoid, and blockades to shoot down. No significance was observed for total maze completion time, but the Belkin n52te trended better than the other devices on all criteria.

15. SUBJECT TERMS
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GLOSSARY

RPA	Remotely Piloted Aircraft
SCIMR	Supervisory Control Information Management Research

PREFACE

This study was performed under work unit 71840919 in support of the Supervisory Control Information Management Research (SCIMR) program. The objective of this study was to determine the effectiveness of two-handed coordination input devices relative to the standard mouse on a complex scenario that involved performing two independent task sets simultaneously.

1.0 INTRODUCTION

The Air Force is seeking to improve capabilities with fewer manpower resources. To this end, automation is being investigated for its potential as a force multiplier (*). This is most certainly the case for remotely operated sensors. If remotely managed systems supervisory controllers have to perform the same missions with fewer personnel, then they would need augmentation from other sources, such as automation. Another method by which to aid operators is to provide them with apt input devices and effective interface configurations. The SCIMR program is investigating the effectiveness of various input devices as alternatives to a standard mouse or stick-and-throttle. The current study is aimed at determining the performance and efficacy gained by using intuitive, fluid movements and coordinated two-handed inputs.

Dependable methods for analysis of input methods fall into four categories: completion time, degree of error, training time, and ergonomics (Zhai, 2009). So far, the best mechanism for studying input device performance is the use of Fitts' law (Fitts, 1954). Fitts' law is a model of human movement in ergonomics and human-computer interaction that predicts that the time required to quickly move to a target area is a function of the size and distance of the target. Fitts' law is used to model the act of pointing, either by physically touching an object with a finger or hand or virtually by pointing to an object on a display using a pointing device (e.g., mouse, light pen, control stick). Fitts' law is of limited use for some complex tasks as it can only be applied to pointing tasks (Accot & Zhai, 1999). The current study seeks to augment Fitts' law with the use of trajectory-based evaluations and those involving steering law. Steering tasks and trajectory-based tasks aim to analyze controller movement of a cursor around a display (Accot & Zhai, 1999). These analyses, however, will be tied to perceived UAS supervisory control scenarios. The Supervisory Control Information Management Research (SCIMR) program has identified the need to evaluate various input devices for the most efficient interaction with current and future interface and control station technologies. This study seeks to further understanding of input devices' characteristics and effectiveness relevant to RPA control. This will be accomplished by understanding the capabilities of hotkey/keyboard and multi-touch/gesturing interactions as well as bimanual coordination and multi-tasking.

Keyboard Shortcuts (Hotkeys)

In the multi-RPA scenario, research began investigating the use of aircraft control equipment, such as aircraft simulator joysticks. Recently, research has been conducted in the multi-RPA field using the standard mouse due to its unrivaled performance in human-computer interactions.

There are, however, emerging technologies may provide improvements in efficiency and effort coordination. "Gamers" have been using keyboard shortcuts, or hotkeys, on standard and specialized gaming keyboards for years in common role-playing games that require coordination of semi-autonomous entities. Larry Archer describes a hotkey as "a keystroke or combination of keystrokes that is used in a Graphical User Interface (GUI) to carry out some operation that would otherwise be executed with the mouse, by clicking on any number of graphical menus, buttons, widgets, toolbars, or icons" and mentions that hotkeys enable some commands to be carried out more efficiently than they would be with a mouse (2008).

Multi-touch/Gesturing

Multi-touch technology is growing in popularity in a variety of environments because of its proven effectiveness for interfacing in two dimensions (Chang, Stuart, & Plimmer, 2009). Multi-touch monitors and touchpads enable the use of natural hand gestures to perform complicated interactions with ease (Nacenta, Baudisch, Benko, & Wilson, 2009). The fact that gestures are used effortlessly in interpersonal interactions makes their use desirable in human-computer interactions. Currently, multi-touch monitors are used in collaborative settings as interactive displays and provide an attractive option for managing media files (Apted, Kay, & Quigley, 2006). The capabilities of this technology cannot be ignored for the management of multiple entities, sensor feeds, and time-relevant data.

Bimanual Coordination

Athletics and motor vehicle operation illustrate two examples of complex tasks that require coordination of multiple extremities. In projected multi-RPA control stations, operators simply use a right-handed mouse or a right-handed joystick with no other control implements. The implementation of the joystick and mouse in the current configuration is due to availability and bias, not due to any usability testing; users are familiar with using a stick-and-throttle configuration in the realm of aviation and a standard mouse in office settings. It should be expected that there will be a significant performance increase in UAS operation when the workload can be divided between both hands, as utilizing two hands to perform complicated tasks is second nature to most human beings. As Albert and Ivry explain, "People are quite skilled in coordinating the gestures of the hands to achieve a common goal" (2009). It can also be noted that two hands enable better performance when manipulating two points (Moscovich & Hughes, 2008).

METHODS

Participants

Participants included 30 Civilian and military employees located at Wright-Patterson AFB, OH. After examination of the data, 2 participants were removed from the analyses due to extreme scores on their response times. The sample consisted of 18 males and 10 females. They were placed in age groups, with 16 participants between 18 and 25 years of age, 8 participants between 26 and 35 years of age, 1 participant between 36 and 45 years of age and 2 participants who were 45 years of age or older. Both were in the Touch device condition. Participants were required to have normal vision (20/20) or corrected-to-normal vision in both eyes and normal color vision. Visual acuity and color vision were determined by participant self report.

Hardware

The test configuration consisted of a multi-touch capable 3M monitor (1680 x 1050 pixel resolution). Three input configurations were evaluated: 1) standard mouse, 2) standard mouse with Belkin n52te, and 3) 3M multi-touch display M2256PW. See figures 1 through 3.

Figure 1. Standard mouse (baseline). The mouse was manipulated with the right hand alone to interact with the entire screen.

Figure 2. Standard mouse with Belkin n52te. The mouse was operated with the right hand to interact with the secondary tasks that appeared on the right side of the screen. The hotkeys of the Belkin n52te were operated with the left hand to interact with the primary task on the left side of the screen.

(Image from 3M's web site.)

Figure 3. 3M multi-touch display M2256PW. The multi-touch monitor was operated via gestures, and participants could use either hand or both hands to interact with primary and secondary tasks.

Mapping

There were five primary task functions that were mapped to each configuration: 1) vehicle movement, 2) tractor beam engagement, 3) color selection, 4) shield engagement, and 5) shooting blockades. These mappings are described below.

Vehicle Movement

- Mouse: Single click caused the vehicle to move in a straight line to the point of the click (discrete control)
- Hotkey: Pressing the directional pad (d-pad) caused the vehicle to move in the direction pressed; releasing the d-pad stopped movement (continuous control)
- Gesture: Tapping on the screen (single click) caused the vehicle to move in a straight line to the point of the tap (discrete control)

Tractor Beam

- Mouse: Scrolling wheel forward/away from user
- Hotkey: 10
- Gesture: 4-5 finger grabbing motion

Color Selection

- Mouse: Right click to open menu, select from menu
- Hotkey: 3 (red), 4 (yellow), 5 (green)
- Gesture: Two-finger swipe up for red, horizontally for yellow, down for green

Shield Engagement

- Mouse: Scrolling wheel backward/toward user
- Hotkey: 9
- Gesture: One-finger arcing motion

Shooting Blockades

- Mouse: Center/wheel click
- Hotkey: 8
- Gesture: One-finger downward flick

Figure 4. Standard mouse function mapping. The standard mouse mainly required left-clicking for interaction. A right-click menu was used to change color, as that is the typical manner by which a mouse can select menu items anywhere on a screen.

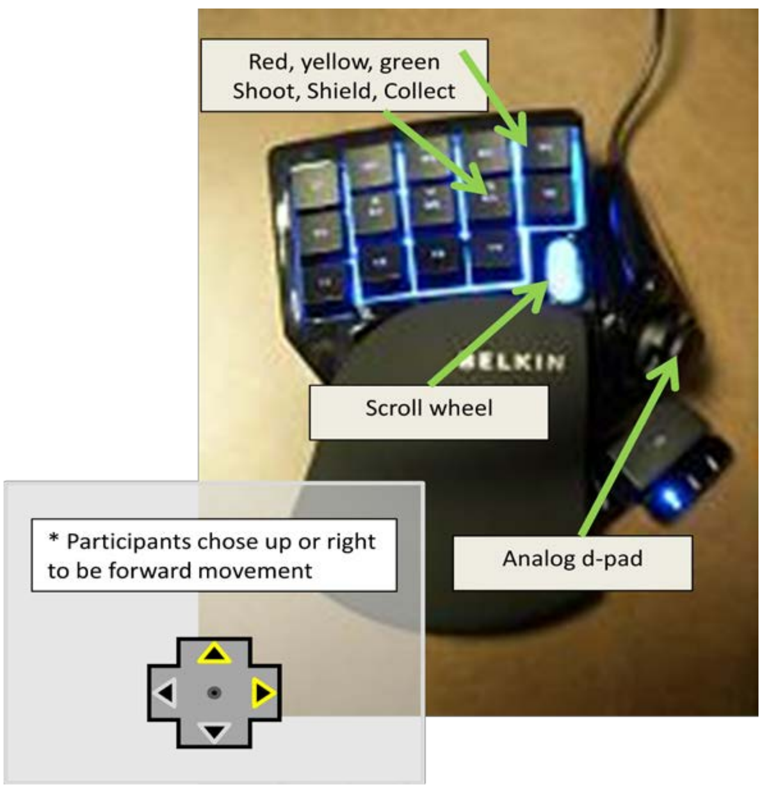


Figure 5. Belkin n52te mappings and layout. Participants were given the opportunity to decide whether the "up" or "right" buttons on the directional pad (d-pad) would move the cursor upward on the screen, with all of the other buttons corresponding to that orientation. This was

due to the placement of the thumb on the d-pad and the d-pad's angle relative to the rest of the game pad. Due to these factors, some people felt that pushing "right" would move the cursor upward, and so on.

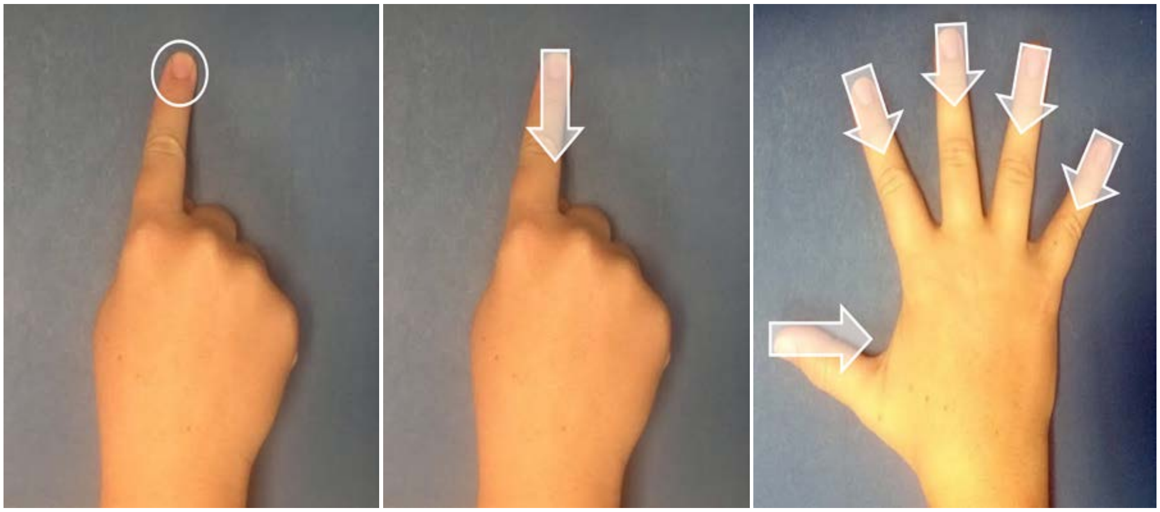


Figure 6. Gestures for moving, shooting, and grabbing (right hand). The pictures illustrate the single-finger tap to move, downward single-finger swipe to shoot a missile, and 4 or 5 digit "grabbing" motion to collect a treasure. Participants could use either hand to perform these gestures.

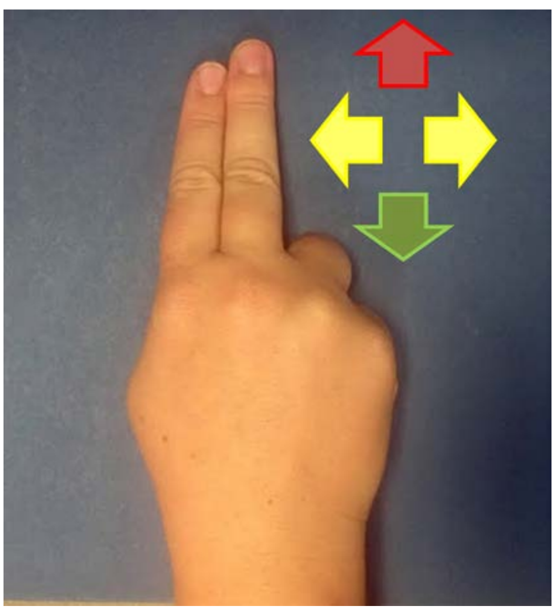
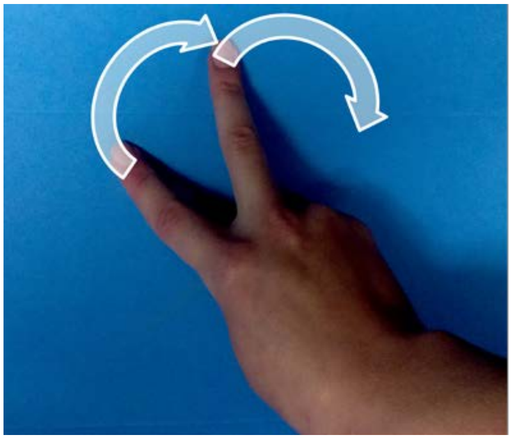


Figure 7. Color selection gestures (right hand). Participants could use either hand with 2 digits swiping upward for red, left or right for yellow, or downward for green.



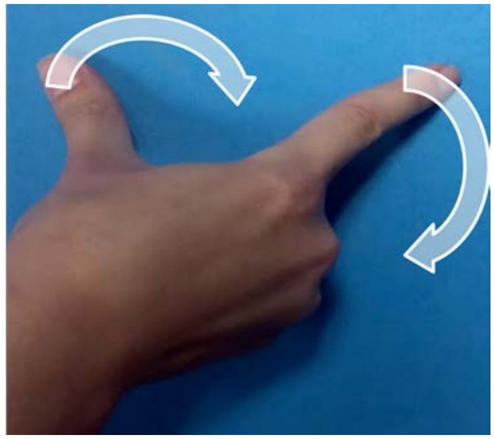


Figure 8. Shield engagement gestures. Participants could use either hand, moving 2 digits in simultaneously in an arching motion to turn on the shield. These two illustrations represent the most common hand positions used.

Secondary tasks were performed with the right-hand-use standard mouse for the standard mouse and standard mouse and Belkin n52te conditions. Participants using the multi-touch monitor were able to use either hand as they deemed necessary. Table 1 describes the secondary task function mappings of each configuration.

Table 1. Secondary task mappings.

Device	Sequence Click	Dragging	Tracking	Zoom-in	Zoom-out
Standard mouse	Depress left mouse button	Depress and hold left button to drag, release left button to release	Move mouse to maintain cursor position over circle	Scrolling wheel forward/away from user	Scrolling wheel backward/toward user
Mouse & Belkin n52te	Depress left mouse button	Depress and hold left button to drag, release left button to release	Move mouse to maintain cursor position over circle	Scrolling wheel forward/away from user	Scrolling wheel backward/toward user
3M multi-touch display M2256PW	Tap screen over desired square	Place finger and maintain contact to drag, lift finger to release	Maintain contact on monitor with finger over circle	Spreading two fingers apart	Pinching two fingers together

Measures

Data collection included demographic data, objective task performance, workload via the NASA Task Load Index (NASA TLX), and subjective ratings of the utility of the devices for performing the experimental tasks. Copies of the study questionnaires are provided in Appendix A.

Demographic data. This questionnaire elicited information about participants' age, sex, vision, video game experience, and input device experience. Device experience level ratings used a 5-point scale: 1-very low, 2 - low, 3 - average, 4 - high, 5 - very high.

Primary Task performance. Objective performance for the maze evaluated time and errors to assess overall efficiency. Time through the maze and time under attack were the *time* measures. Errors were defined as touching maze boundaries (walls and blockades) and failing to implement requisite actions with appropriate stimuli.

Table 2. Primary task stimuli and required responses.

Stimulus	Response
Treasure	Pick up with tractor beam
Enemies	Switch to appropriate enemy color and engage shield
Walls	Shoot to knock over

Secondary Task Performance. The secondary task performance characteristics that were assessed were the total time from task appearance to task completion, the delay between task appearance and initial interaction with it, and the number and duration of secondary task interruptions- defined as leaving the secondary task (in progress) to interact with the maze.

Subjective ratings. After each trial, participants completed the NASA Task Load Index (NASA TLX) to assess perceived workload. Following completion of both trials, the N and spiral mazes, participants were asked open-ended questions about how they felt the device helped them perform on the N maze, spiral maze, and secondary tasks. Participants were asked to provide comments regarding the strengths and weaknesses of the device and suggestions for modifications.

Procedures

Each session began with a briefing regarding the study objectives and completion of the informed consent document and demographic questionnaire. Following the introduction, participants underwent training for their respective devices. Participants trained until they met the requirements to proceed to the trial mazes. During the course of the data collection, participants completed 2 trials, one with a spiral and one with an N-shaped maze. Each trial was defined by a maze task combined with a set of 5 secondary tasks. The sequence of events was the same for all participants, but the maze order was counterbalanced, meaning that every other participant received the spiral maze before the N maze. Following each trial, participants completed a NASA TLX for that maze. At the conclusion of both trials, participants completed a post-session questionnaire. The entire session required an average of an hour including the introductory briefing, informed consent, training, two mazes, and questionnaires.

At the test station, each participant received detailed training in all of the procedures to be employed during the entire experiment. First, participants were given an introductory briefing on the primary and secondary tasks to include a description of objectives, feedback mechanisms, and performance analysis methods. Training progressed from proving proficiency with each individual task (encompassing all of the maze actions and the secondary tasks outlined in the "Mapping" section) to small task sequences (i.e., change color then engage shield) and, ultimately, performing primary (maze) actions and secondary tasks simultaneously. Participants were prompted by on-screen text instructions. They attempted each task/action until it was performed correctly 5 times in a row, or until a minimum success rate of 70% out of 10 trials was achieved. If this success rate was not achieved in the first 10 trials, participants continued attempting the task/action until the success rate increased to 70% or the task/action was performed correctly 5 times in a row.

Prior to the beginning of each trial, there was a screen prompting "Click to begin trial". Clicking caused the maze to appear. After a three second countdown, (visually represented in the center of the screen) which allowed the participants to quickly familiarize themselves with the maze's layout, the participants were able to interact with the maze and the timers began.

The task set involved successfully completing a maze that had obstacles to overcome and objectives which participants had to accomplish. The maze was on the left side of the monitor and additional, secondary tasks were performed on the right. Maze completion was dependent upon successfully accomplishing all prescribed tasks while still reaching the end.

The primary task was a maze on the left side of the screen. Completion of the maze involved overcoming obstacles with the use of assigned gestures, hotkeys, or menus, as well as completing secondary tasks on the right side of the screen with the main device. Secondary tasks did not have to be performed immediately and could have been stacked in a queue. Bimanual coordination was encouraged by putting a limit on the number of secondary tasks available for completion; if the queue reached five tasks, participants were unable to make progress in maze completion until a secondary task was performed, preventing them from focusing solely on the primary task.

Designs for primary and secondary tasks were derived from integrating Fitts' law and steer point analysis in conjunction with a test created by Armbrüster et al. (2007). Other design considerations were derived from contemporary and foreseeable multi-RPA supervisory control and sensor management environments.

Primary Tasks

Participants were tasked with completing a spiral maze as well as an 'N' shaped maze. Maze interactions included gathering treasures, blocking enemies with the appropriate shield and color responses, and knocking down walls that blocked progress. Acquiring a treasure triggered the appearance of a secondary task on the right side of the screen. Enemies of three colors, red, yellow, and green progressed from the end of the maze to the beginning. Participants had to select the color which matched that of the oncoming enemy and engage the shield in order to progress; failure to do so resulted in the enemy pushing the maze vehicle back toward the beginning of the maze until the shield and/or correct color was engaged. The maze also contained walls that had to be shot down in order to proceed. Furthermore, participants were instructed to avoid hitting maze walls as these were recorded as errors.

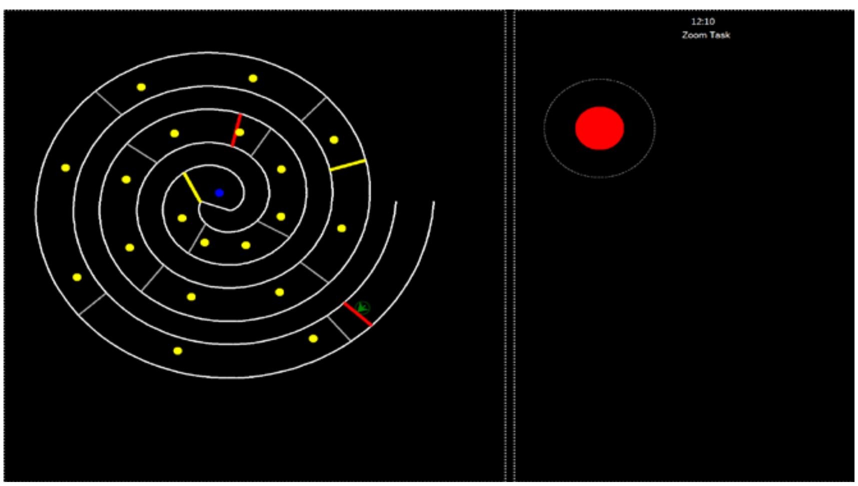


Figure 9. Spiral maze with secondary task.

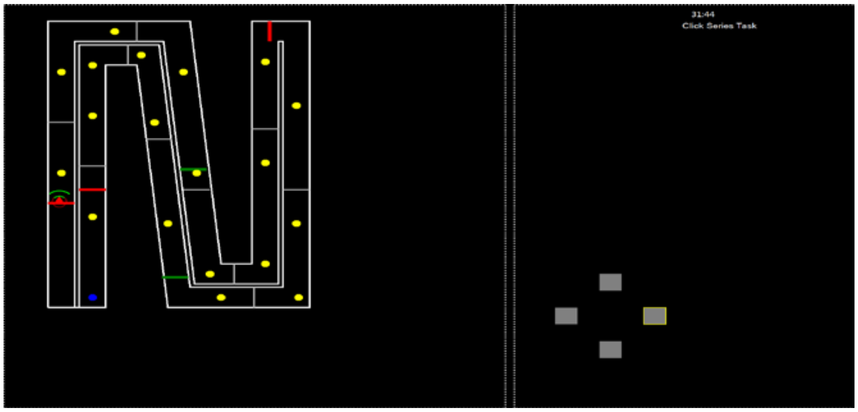


Figure 10. N-shaped maze with secondary task.

Secondary Tasks

Secondary tasks were selected based on computer movements and interactions seen in current and foreseeable RPA and sensor operation using a TSD.

Table 3. Secondary tasks. Secondary tasks were derived from sensor operation-based computer interactions.

Secondary Task	**Analogous Task**
Sequence click	Navigating a menu, flagging targets
Dragging	Manipulating DVR controls, interacting with TSD (range and bearing, etc.)
Tracking	Following target in the sensor feed (target speed emulates the approximate speed of a person walking across the view of a sensor feed)
Zoom in	Self-explanatory
Zoom out	Self-explanatory

Secondary Task Descriptions

<u>Sequence click</u>

A grey box appeared in the secondary task area. The task timer began when the participant first clicked on the grey box. Four boxes appeared around the cursor, one of which was highlighted in yellow. Upon clicking the highlighted box, the box disappeared and the yellow outline appeared on one of the remaining boxes. The participant had to click each of the highlighted boxes in turn until all four boxes were gone. When the last box was clicked, the timer stopped, and the task was complete.

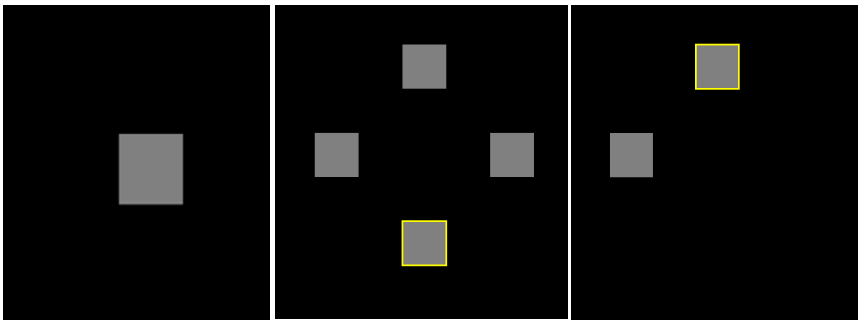


Figure 11. Sequence click task.

Dragging

A yellow circle and a grey circle with a short grey line attached to a smaller circle appeared in the secondary task area. The task timer began when the participant clicked on the smaller grey circle. Upon being clicked, the circle and adjoining line turned blue to indicate that they were under the participant's control. The participant had Drag the (then blue) circle to the yellow target circle and release. Upon release of the blue circle inside of the yellow circle, both circles disappeared, the timer stopped, and the task was complete.

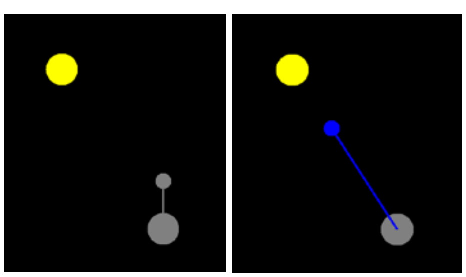


Figure 12. Dragging task.

Tracking

A yellow circle appeared in the secondary task area. The task timer began when the participant moved the cursor/his or her finger over the circle. Once contact with the circle was made, the circle turned red with a red ring around it and moved in a predetermined straight line across the secondary task area. The longer the participant maintained contact with the circle, the faster the circle moved; removing the cursor/his or her finger from the circle caused it to stop. Upon reaching the end of the predetermined path, the circle disappeared, the time stopped, and the task was complete.

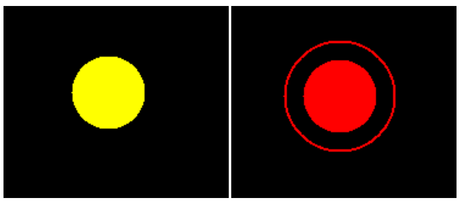


Figure 13. Tracking task.

Zoom-in

A small yellow circle and the outline of a larger circle appeared in the secondary task area. The task timer began when the participant clicked on the yellow circle and the yellow circle turned red. The participant had to zoom in on the red circle until it matched the larger outline, at which point the circle turned green. Once it turned green, the participant had to left-click or one-finger tap on the monitor in the multi-touch condition. After tapping, the circle disappeared, the timer stopped, and the task was complete.

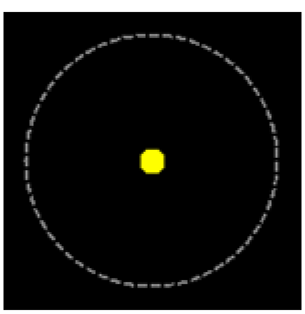


Figure 14. Zoom-in task.

Zoom-out

A large yellow circle and the outline of a smaller circle appeared in the secondary task area. The task timer began when the participant clicked on the yellow circle, turning it red. The participant had to zoom out on the red circle until it matched the smaller outline and turned green-- at which point both circles disappeared, the timer stopped, and the task was complete.

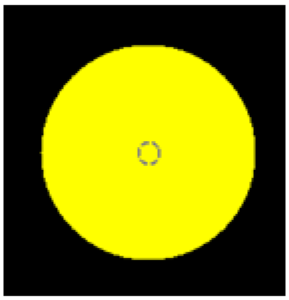


Figure 15. Zoom-out task.

Analyses

In the analyses of the data for Hypothesis 1, the standard mouse was treated as a baseline condition against which the effectiveness of the other two control devices was evaluated. This required a directional (one-tailed) test for the assertion that a two-handed device would enable better performance than the one-handed mouse. As for the second hypothesis, there was no clear expectation of how performance would be affected by the type of two-handed control device, and as a result, non-directional (2-tailed) tests were used. Analyses of variance (ANOVAs) were used to compare mean performance for the three devices (Mouse, Mouse/Belkin, and Touch) on several objective task performance measures and for the subjective ratings of workload. All statistical tests used a 0.05 Type I error rate.

RESULTS

Task Performance

Table 2 summarizes the means, standard deviations, and ANOVA results comparing the Maze Completion Time (MCT) for the three input devices. MCT was measured in seconds to complete each maze and averaged across the N-shaped and spiral-shaped mazes. As shown in Table A, MCT was not significantly affected by the input device used.

Table 4. Mean Completion Time (in seconds): Means, SDs, and ANOVA.

Scale	Device	N	Mean	SD	F (2, 25)	Probability
Maze Completion Time	Mouse	10	417.18	74.71	2.57	.096
	Mouse/Belkin	10	389.36	91.26		
	Touch	8	485.61	107.86		

Latency Time for Secondary Tasks

Latency time was calculated for several secondary tasks involving click series, dragging objects, tracking objects, and zooming. The tasks involving tracking are not included in Table B due to a scoring error for that task involving the Mouse/Belkin device. In the 2 instances where a significant effect was observed, Touch was less efficient than the Mouse or Mouse/Belkin devices: Drag – Completion ($F(1, 25) = -4.21$, $p < .001$); Zoom Completion ($F(1, 25) = -3.58$, $p < .001$).

Table 5. Latency Time (in seconds) for Secondary Tasks: Means, SDs, and ANOVAs.

Scale	Device	N	Mean	SD	F (2, 25)	Probability
Click Series	Mouse	10	1.65	0.61	0.43	.651
	Mouse/Belkin	10	1.87	0.60		
	Touch	8	1.70	0.44		
Drag	Mouse	10	1.20	0.58	1.27	.297
	Mouse/Belkin	10	0.86	0.43		
	Touch	8	1.09	0.38		
Zoom	Mouse	10	1.70	0.66	0.48	.622
	Mouse/Belkin	10	1.87	0.58		
	Touch	8	1.60	0.52		
Drag - Completion	Mouse	10	1.10	0.21	8.87	.001
	Mouse/Belkin	10	1.13	0.58		

	Touch**	8	2.22	0.95		
Zoom - Completion	Mouse Mouse/Belkin Touch	10 10 8	1.39 1.44 2.05	0.25 0.38 0.59	6.47	.005

Other Task Performance Measures

Several other task performance measures were examined. There were: Goal Collection – Number of Excessive Tractor Beams, Blockades destroyed – Number of Missiles Launched, Collisions – Total, Color Changes, Attacks Failed – Shield, Attacks Failed – Color, Attacks Failed – Shield & Color, Attacks Failed – All Reasons, and Attacks – Average Duration. Results of the ANOVAs comparing the three devices are summarized in Table D. Significant effects were observed for several scores; however where significant differences occurred, they did not always favor the same device. Goal Collection was significantly less efficient for the Mouse than the other devices, requiring more tractor beams. The Mouse/Belkin device resulted in significantly more Collisions and Color Changes than the other devices. Attack performance was poorest for the Touch device where statistically significant effects were observed for 4 of the 5 Attacks performance scores.

Table 6. Other Task Performance Measures.

Scale	Device	N	Mean	SD	F (2, 25)	Probability
Goal Collection: N Excess Tractor Beams	Mouse Mouse/Belkin Touch	10 10 8	71.10 17.70 21.63	27.59 10.73 18.00	21.18	.000
Blockades Destroyed: N Missiles Launched	Mouse Mouse/Belkin Touch	10 10 8	6.30 7.00 4.38	5.81 4.44 2.72	0.75	.483
Collisions: Total	Mouse Mouse/Belkin Touch	10 10 8	43.40 88.80 55.25	27.04 54.68 13.94	3.93	.033

Color Changes	Mouse Mouse/Belkin Touch	10 10 8	1.50 35.20 7.00	2.75 17.31 3.66	28.03	.000
Attacks Failed: Shield	Mouse Mouse/Belkin Touch	10 10 8	23.50 12.20 40.87	9.95 7.31 16.54	13.93	.000
Attacks Failed: Color	Mouse Mouse/Belkin Touch	10 10 8	8.40 4.60 7.50	7.12 3.23 5.60	1.26	.300
Attacks Failed: Shield & Color	Mouse Mouse/Belkin Touch	10 10 8	20.00 8.80 40.50	12.54 6.97 27.96	7.70	.002
Attacks Failed: All Reasons	Mouse Mouse/Belkin Touch	10 10 8	51.90 25.60 88.87	26.66 14.69 45.25	9.82	.001
Attacks: Average Duration	Mouse Mouse/Belkin Touch	10 10 8	0.15 0.13 0.17	.02 .02 .01	7.75	.002

Subjective Workload

Table E summarizes the means, standard deviations, and ANOVAs comparing the 3 input devices for the NASA TLX scales and Overall Workload. The mean Overall Workload across all three conditions was moderate at 56.20. The highest mean scores across conditions occurred for the Mental Demand (66.96), Temporal Demand (63.88), and Effort (66.33) scales. Subjective workload ratings were not affected by the input device used to perform the various tasks.

Table 7. Subjective Workload: Means, SDs, and ANOVAs.

Scale	Device	N	Mean	SD	F (2, 25)	Probability
Mental Demand	Mouse Mouse/Belkin Touch	10 10 8	64.50 69.12 67.34	18.73 24.26 11.77	0.14	.867
Physical Demand	Mouse Mouse/Belkin Touch	10 10 8	40.37 35.62 41.87	27.92 26.68 31.01	0.12	.885
Temporal Demand	Mouse Mouse/Belkin Touch	10 10 8	59.87 70.37 60.78	23.06 23.39 15.56	0.72	.496
Performance	Mouse Mouse/Belkin Touch	10 10 8	53.25 48.87 53.75	12.13 27.22 9.63	0.19	.822
Effort	Mouse Mouse/Belkin Touch	10 10 8	61.00 68.62 70.15	18.37 21.92 12.72	0.66	.522
Frustration	Mouse Mouse/Belkin Touch	10 10 8	59.75 45.00 53.75	16.09 28.79 25.03	0.96	.393
Overall Workload	Mouse Mouse/Belkin Touch	10 10 8	55.37 56.64 56.69	14.28 19.58 13.42	0.02	.980

Subjective Performance Ratings

There were no significant results for perceived performance, neither by maze type, nor device configuration. Summaries of the subjective ratings are provided in tables B-1 and B-2.

DISCUSSION

Contrary to predictions, there were no significant differences in maze times among device configurations. It was expected that the use of two hands would ensure better reactions to stimuli and decrease the time required to complete the mazes. The fact of the matter was that the Belkin n52te yielded slower maze times on the spiral maze with significantly more wall and blockade hits than the standard mouse alone and the multi-touch monitor. The n52te actually performed significantly better on the N-shaped maze than it did on the spiral maze, indicating that the device was lacking in the ability to perform angular and diagonal cursor movements efficiently. This was due to the device's cursor movement control being a d-pad instead of using the click-to-move implementation like that of the standard mouse and multi-touch monitor.

The main stimulus-response interaction that was found to impact maze performance, aside from movement, was that of progressing through the attackers. Participants had to see the color of the attacker, change the color of the cursor, and engage the shield. Due to the randomness of the attackers' color and the frequency of their appearance, participants' cursors would often get hit or pushed back by them while they focused on secondary tasks. The mouse with Belkin n52te performed significantly better than the multi-touch monitor, but there was no significance between the standard mouse alone and the mouse with Belkin n52te. However, the standard mouse with Belkin n52te trended better than both the multi-touch monitor and the standard mouse alone. The mouse with Belkin n52te configuration had significantly fewer shielding errors (fewer incorrect inputs per correct response), significantly shorter attack durations (less time being pushed backwards by attackers), and significantly fewer failed attacker responses (failure to implement the correct color and engage the shield prior to encountering an attacker) than the multi-touch monitor. The mouse with Belkin n52te trended better than the other configurations in all attack-response criteria. The color-change hotkeys enabled instantaneous color changes that were quicker and required less effort than gestures and menu selections. As the same was true for shielding, many participants were recorded performing secondary tasks and responding to attackers simultaneously with the mouse and n52te.

The multi-touch monitor was worse than the other implementations in terms of total maze time and attack duration. This was partially impacted by the fact that gestures required more effort to perform. The reasons for the longer multi-touch maze times were failed attack responses and longer attack durations. Poor attack responses were due to the inflexibility of the mappings of the monitor and the complexity of the gestures. Participants indicated frustration that their commands were not being read and that they needed to be re-entered multiple times, in some cases, before registering with the system. There were two gestures in particular that averaged significantly more failed attempts per registered command, yellow color change and shielding. Yellow color change and shielding both required roughly horizontal two-finger movement. There was not enough flexibility for gesture recognition patterns and pressure on the screen to allow for the fingers and their paths to register. The chosen gestures for shielding and color change overall were too arduous to perform constantly in such a dynamic environment. There also needs to be tolerance by the monitor for pressure and a smoother surface to enable the user to execute commands under duress. Participants would press harder when stressed and their fingers would skip on the screen or not be registered. That would not be acceptable in an operational setting wherein stressful situations are common. The number of fingers required for a gesture did not appear to be of any consequence. The 4 to 5 finger "grabbing" gesture for engaging the tractor beam did not have any issues due to the fingers being spaced and not having to be moved awkwardly. The simple take-away is to keep the gestures confined to small dragging and tapping motions while allowing for more error in gesture patterns.

An area of interest for the standard mouse and standard mouse with Belkin n52te condition was excessive inputs. Excessive inputs were likely the sign that participants were either not totally aware of the placement of their digits or comfortable with the devices' mappings. This was measured by subtracting the minimum required inputs to complete both mazes from the actual amount that participants performed. The mouse had significantly higher occurrences of excessive shielding and tractor beam engagement errors. This was probably due to participants' interpretations of those actions relative to their inputs. Participants often stated that the tractor beam animation being at the front of the cursor made them want to hit forward on the scroll wheel. The result was that participants would often scroll both forward and backward on the mouse's scroll wheel to perform one instance of shielding, and more commonly, picking up a treasure. Excessive color change was prominent with the Belkin n52te as participants would often lose their finger positions on the keyboard, or forget which buttons changed the cursor color to red or green. Since red and green were on opposite sides of the button for yellow, participants would get them confused. There were, however, significantly fewer occurrences of excessive input for turning the cursor yellow. A method that would likely aid in maintaining hand position and button function recall could be the use of heterogeneous buttons. Just as with joysticks and game controllers, distinct buttons and other input options could decrease the occurrence of incorrect input usage. Participants could relate the distinct input mechanisms to their functions, which could maximize hotkey performance.

The device training requires further adjustment. Though, participants were trained to a standard, Belkin n52te buttons were not fully memorized and touch-screen gestures were not performed consistently during data collection trials. In order to account for the common use of the standard mouse, training must most likely become more stringent. Further research must rely on distributed training that occurs in the days before data collection. This would ensure a higher degree of comfort, familiarity, and efficiency with a novel device. As with any study of this nature, researchers must overcome years of daily participant experience with the standard mouse to ensure that device characteristics, not familiarity, determine actual performance potential.

This research has shed light on many different issues which require further delving. The most glaring of which is the mapping and software integration. The limitation of the multi-touch monitor was that it was state-of-the-art and there was very little information available for developing on it. Workarounds limited the flexibility of the gesture recognition and hindered performance. Further research must either require simpler interactions or better methods by which to implement complex inputs. These concepts must be applied to get a valid notion of the possibilities multi-touch can afford. Another manner by which to assess the value of multi-touch would be to integrate it with other modalities. A configuration that combines a multi-touch monitor with a game pad, like the Belkin n52te, or speech recognition software might be a way to increase human-computer interaction performance.

Upon definition of apt technologies for bi-manual input, testing should involve a simulated operational scenario. Only by testing performance on a relevant task set can the effectiveness of devices for remote entity control be gauged. The combination of these input options could prove effective on a complex, dynamic task set. Multi-touch could be utilized with referential gestures to enable the performance of intuitive commands on a complex display with a dynamic scenario. Hot keys could be integrated with multi-touch and/or speech control as well to aid performance.

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Appendix A
Study Questionnaires

Demographic Questionnaire

Is your vision 20/20 or correctable to 20/20?		Yes	No	
What is your handedness?	Right	Left	Ambidextrous	
In what age group are you?	18-25	26-35	36-45	46+

Please rate your expertise with video games (circle one):

None	I never, or rarely, play video games
Novice	I occasionally play video games
Average	I have my own video game system that I use once or twice a week
Experienced	I enjoy playing video games often and can learn new games easily
Expert	I am very skilled with my favorite types of games and play them a lot

Rate computer/video game experience with the following systems *(1=Very Low, 2=Low, 3=Average, 4=High, 5=Very High)*:

Standard mouse and keyboard (office setting)	1	2	3	4	5
Standard mouse and keyboard (computer gaming)	1	2	3	4	5
Touch screens (used with fingers)	1	2	3	4	5
Touch screens (used with stylus)	1	2	3	4	5
Video game controllers	1	2	3	4	5

(SHORTCUT) NASA TLX Workload Rating Scale

Participant:_______________
Condition:_______________
Maze:________________

Workload Rating Scales

Definitions

Title	End Points	Descriptions
MENTAL DEMAND	Low / High	How much mental and perceptual activity was required (that is, thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low / High	How much physical activity was required (that is, pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Poor / Good	How successful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Please rate your workload by putting a mark on each of the six scales at the point which matches your experience.

Mental Demand

Very Low — Very High

Physical Demand

Very Low — Very High

Temporal Demand

Very Low — Very High

Performance

Very Poor — Very Good

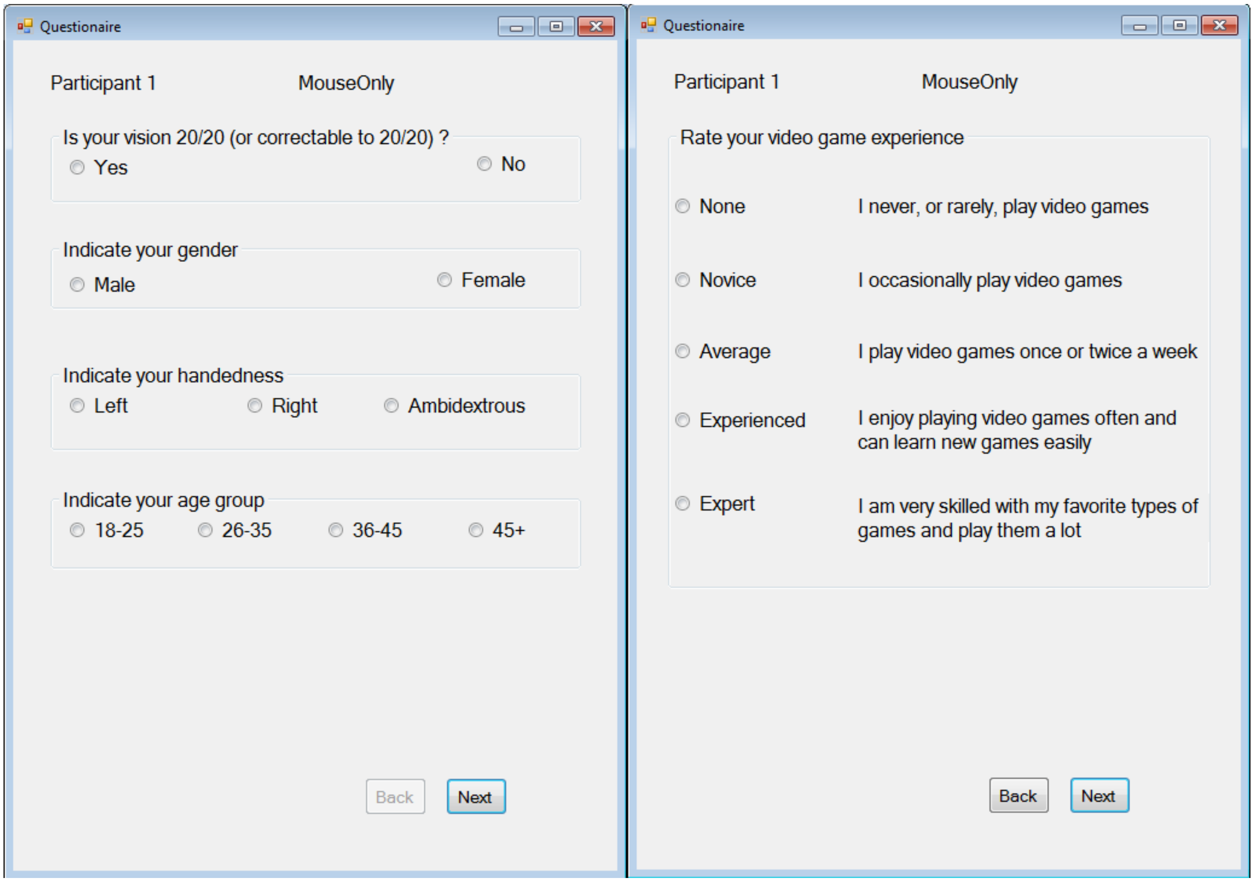
Effort

Very Low — Very High

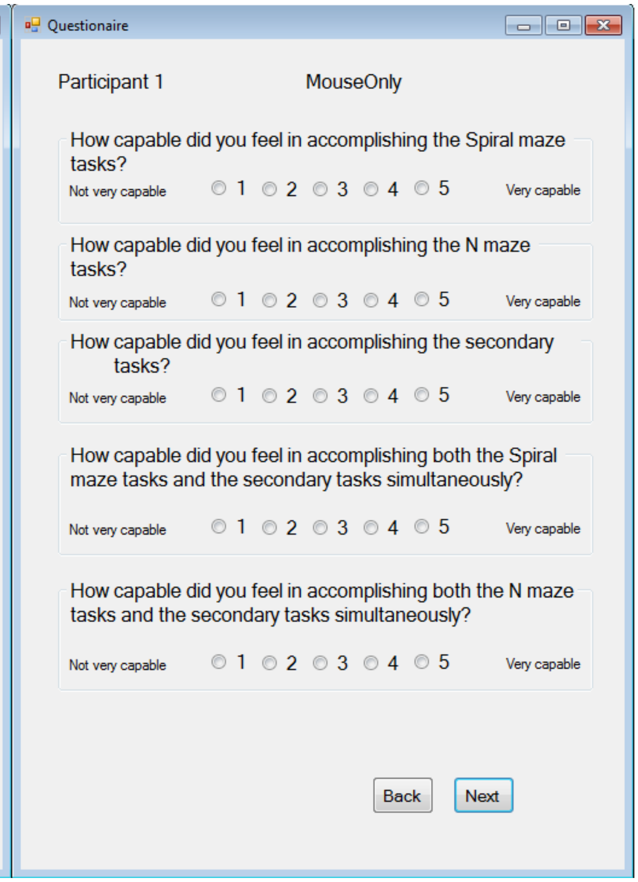
Frustration

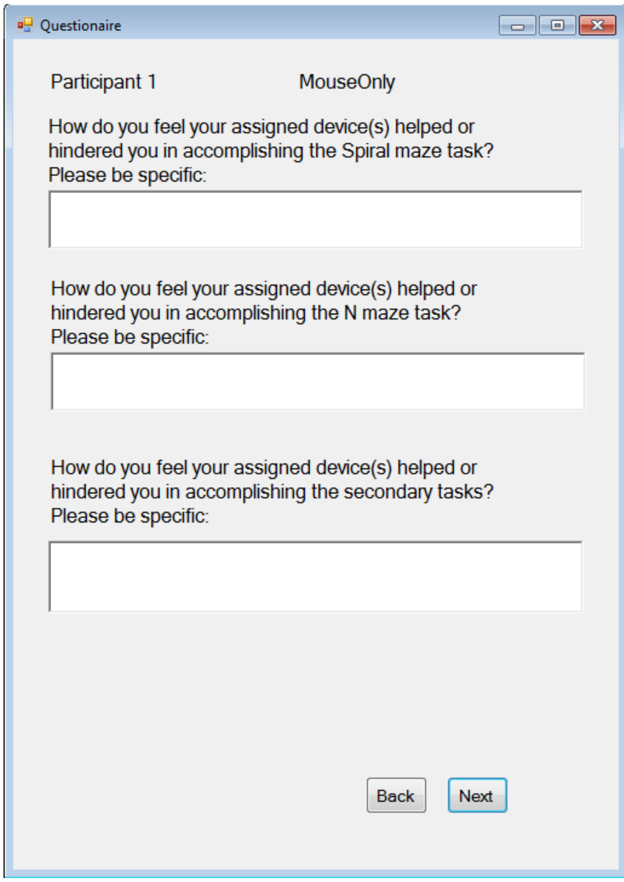
Very Low — Very High

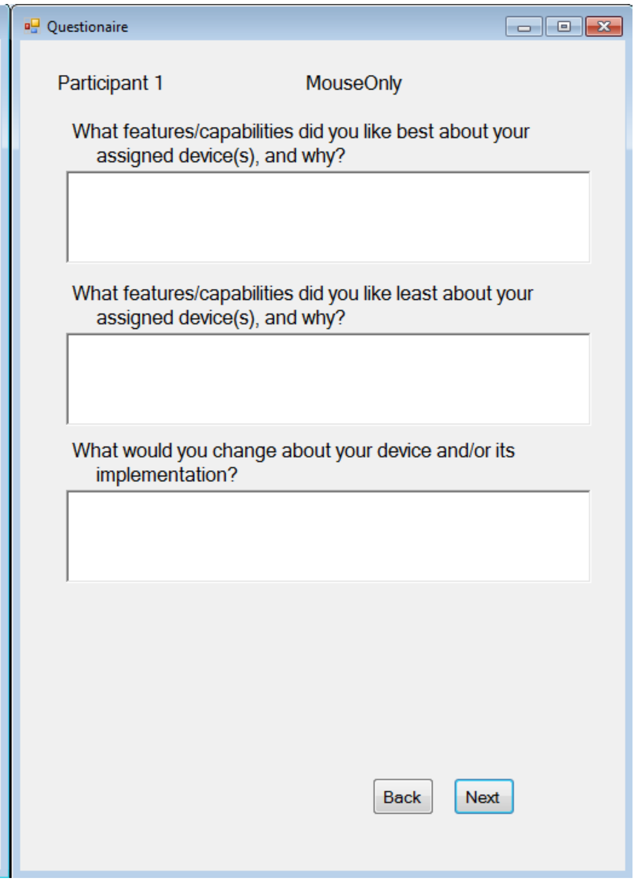
Post Session Questionnaire




Questionaire
Participant 1
MouseOnly
Rate computer/video game experience with the following systems
(1=Very Low, 2=Low, 3=Average, 4=High, 5=Very High)
Standard Mouse/Keyboard (Office Setting)
1 2 3 4 5
Standard Mouse/Keyboard (Gaming Setting)
1 2 3 4 5
Touchscreen (Fingers)
1 2 3 4 5
Touchscreen (Stylus)
1 2 3 4 5
Video Gaming Experience
1 2 3 4 5
Back
Next


Questionaire
Participant 1
MouseOnly
How capable did you feel in accomplishing the Spiral maze tasks?
Not very capable 1 2 3 4 5 Very capable
How capable did you feel in accomplishing the N maze tasks?
Not very capable 1 2 3 4 5 Very capable
How capable did you feel in accomplishing the secondary tasks?
Not very capable 1 2 3 4 5 Very capable
How capable did you feel in accomplishing both the Spiral maze tasks and the secondary tasks simultaneously?
Not very capable 1 2 3 4 5 Very capable
How capable did you feel in accomplishing both the N maze tasks and the secondary tasks simultaneously?
Not very capable 1 2 3 4 5 Very capable
Back
Next


Questionaire
Participant 1
MouseOnly
How do you feel your assigned device(s) helped or hindered you in accomplishing the Spiral maze task? Please be specific:
How do you feel your assigned device(s) helped or hindered you in accomplishing the N maze task? Please be specific:
How do you feel your assigned device(s) helped or hindered you in accomplishing the secondary tasks? Please be specific:
Back
Next


Questionaire
Participant 1
MouseOnly
What features/capabilities did you like best about your assigned device(s), and why?
What features/capabilities did you like least about your assigned device(s), and why?
What would you change about your device and/or its implementation?
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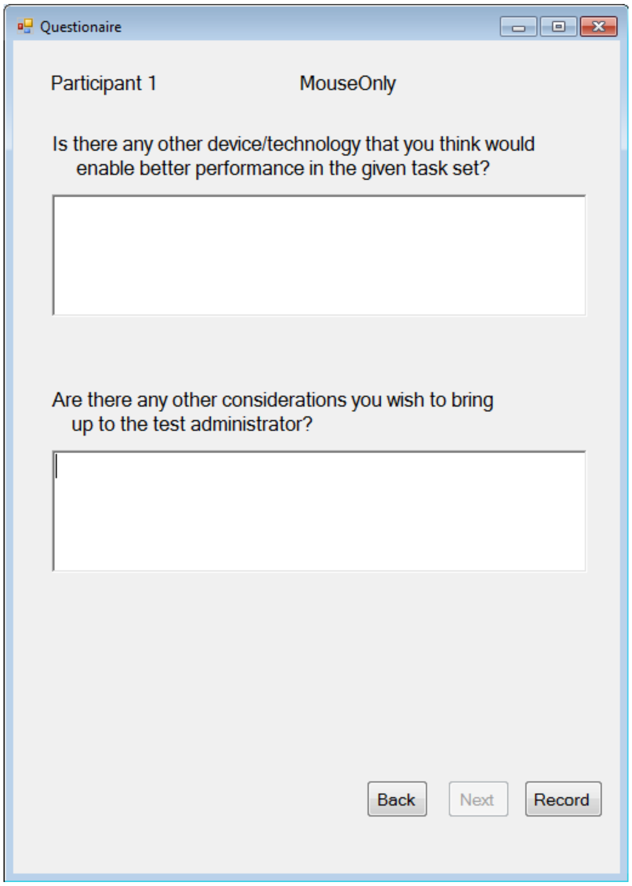
Questionaire
Participant 1
MouseOnly
Is there any other device/technology that you think would enable better performance in the given task set?
Are there any other considerations you wish to bring up to the test administrator?
Back
Next
Record

Appendix B
Subjective Rating Result Tables

Table B-1. Subjective Ratings of Performance: Descriptives.

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
CapableSpiral	Mouse	10	3.10	.738	.233	2.57	3.63	2	4
	Mouse with Belkin	10	3.00	1.155	.365	2.17	3.83	1	5
	Touch	8	3.00	1.069	.378	2.11	3.89	2	5
	Total	28	3.04	.962	.182	2.66	3.41	1	5
CapableN	Mouse	10	3.50	.527	.167	3.12	3.88	3	4
	Mouse with Belkin	10	3.80	1.135	.359	2.99	4.61	1	5
	Touch	8	3.63	.518	.183	3.19	4.06	3	4
	Total	28	3.64	.780	.147	3.34	3.95	1	5
CapableSecondary	Mouse	10	4.30	.483	.153	3.95	4.65	4	5
	Mouse with Belkin	10	4.00	1.155	.365	3.17	4.83	2	5
	Touch	8	3.88	.641	.227	3.34	4.41	3	5
	Total	28	4.07	.813	.154	3.76	4.39	2	5
CapableSi	Mouse	10	2.80	.919	.291	2.14	3.46	1	4

mulSpiral	Mouse with Belkin	10	2.30	1.337	.423	1.34	3.26	1	5
	Touch	8	2.13	1.126	.398	1.18	3.07	1	4
	Total	28	2.43	1.136	.215	1.99	2.87	1	5
CapableSimulN	Mouse	10	3.30	.949	.300	2.62	3.98	2	5
	Mouse with Belkin	10	2.90	1.370	.433	1.92	3.88	1	5
	Touch	8	2.75	1.165	.412	1.78	3.72	1	4
	Total	28	3.00	1.155	.218	2.55	3.45	1	5

Table B-2. Subjective Ratings of Performance ANOVA.

		Sum of Squares	df	Mean Square	F	Sig.
CapableSpiral	Between Groups	.064	2	.032	.032	.968
	Within Groups	24.900	25	.996		
	Total	24.964	27			
CapableN	Between Groups	.454	2	.227	.355	.705
	Within Groups	15.975	25	.639		
	Total	16.429	27			
CapableSecondary	Between Groups	.882	2	.441	.650	.531
	Within Groups	16.975	25	.679		
	Total	17.857	27			
CapableSimulSpiral	Between Groups	2.282	2	1.141	.876	.429
	Within Groups	32.575	25	1.303		

	Total	34.857	27			
CapableSimulN	Between Groups	1.500	2	.750	.543	.587
	Within Groups	34.500	25	1.380		
	Total	36.000	27			